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EVALUATION OF ALTERNATE WIRE FABRIC MATERIALS FOR
ARTICULATED CONCRETE MATTRESSES

Edward Cox, et al

Army Construction Engineering Research Laboratory
Champaign, Illinois

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by
Edward Cox
Christopher Hahin
James Aleszka

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This report presents results of a study of the tensile strength and corrosion resistance of alternate fabric materials which could be used in articulated concrete revetment mattresses to prevent erosion along the Mississippi River. Three groups—stainless steels, bimetallics, and organically coated low-carbon steels—were evaluated.

After 2 years of exposure in the Mississippi River above New Orleans, all the stainless steels possessed enough strength and corrosion resistance to qualify them as substitute

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fabric materials. Of the bimetallics tested, Copperweld* was acceptable as a fabric material while the galvanized wire was rejected because of inadequate adherence of the zinc to the steel when deformed.

All the organic-coated wires passed the tensile requirements although the polyethylene-coated wire failed the field test. Except for the vinyl resin VMCH, all the coatings provide adequate corrosion resistance for carbon steel wire.

*Trademark of Copperweld Corporation.

FOREWORD

This investigation was conducted by the Metallurgy Branch, Materials Systems and Science Division (MS), of the Construction Engineering Research Laboratory (CERL), under reimbursable orders for the Corps of Engineers Lower Mississippi Division (LMVD), Vicksburg (IAO 2994), New Orleans (IAO LMMED-73-3), and Memphis (IAO LMMED-75-12) District Offices. The LMVD Technical Monitor was Mr. J. Graham, LMVED-C.

CERL personnel directly concerned with the study were E. Cox, C. Hahin, J. Aleszka, and Dr. R. Heidersbach.

Dr. R. Quattrone is Chief of the Metallurgy Branch; Dr. W. Fisher is Acting Chief of MS. COL M. D. Remus is Commander and Director of CFRL and Dr. L. R. Shaffer is Deputy Director.

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EVALUATION OF ALTERNATE WIRE FABRIC MATERIALS FOR ARTICULATED CONCRETE MATTRESSES

1 INTRODUCTION

Background

The U.S. Army Corps of Engineers has been successfully reveting the lower banks of the lower Mississippi River with articulated mats for many years. The revetments are composed of wire fabric (Figure 1) cast into concrete slabs to form articulated units (Figure 2). These units are then assembled to form a concrete mattress of designed length and width which is secured to the prepared river banks with steel cables, and placed as shown in Figure 3. The amount of wire required for the annual revetment program is between 80 and 170 million lin ft.

The wire used in revetment fabric must possess corrosion resistance and high strength. At present, two materials have been accepted for this application: American Iron and Steel Institute (AISI) 301 stainless steel and copper-clad carbon steel—specifically Copperweld* wire. However, with the rising cost of nickel and copper and recent technological advances in new materials, the possible existence of other, less costly, materials which can meet the same requirements should be investigated.

Objective

The objective of this study is to evaluate candidate wire fabric materials as alternatives to Copperweld and AISI 301 stainless steel in articulated concrete revetment mattresses. This will increase the number of materials which can perform satisfactorily as wire fabric, increase the number of wire fabric suppliers, and reduce the cost.

This report is limited to wire fabric materials used in articulated concrete mats placed in fresh water on the Mississippi River above New Orleans.

Approach

In this investigation, three classifications of wire fabric materials were evaluated stainless steels, bimetallics, and organic coatings on plain carbon steel. The investigation consisted of (1) selecting probable candidate materials from probable future suppliers, (2) screening the materials for compliance with the mechanical properties specifications provided in the appendix, (3) fabricating them into specimen blocks, (4) exposing them to the Mississippi River for varying time intervals, and (5) evaluating them after exposure. Surface corrosion and deterioration of mechanical properties were evaluated. The stainless steels were also evaluated for resistance to sensitization, which is reduction in the corrosion resistance of stainless steel resulting from welding.

Since the best method of evaluating a material's corrosion resistance to a specific environment is to subject it to that environment, corrosion tests were made in the Mississippi River. Results were compared with those for a standard low-carbon steel and the materials currently permitted in the wire fabric specification.[1]

Only stainless steels, bimetallics, and organically coated low-carbon steels meeting the physical requirements specified in the appendix (except the galvanized wire which failed the wrap test) were chosen for corrosion testing.

The materials were tested in wire form and exposed for time periods ranging from 1 to 36 months. The exposures were made at Delta Point, LA (near Vicksburg, MS) and at a site near New Orleans. The Delta Point samples were lost in the 1973 spring floods.

2 MATERIALS

The stainless steels of interest in this project are low-cost, primarily low-nickel, stainless steels. Three austenitic stainless steels (AISI 201, AISI 310, and Armco 18-2), one ferritic stainless steel (AISI 430), and one martensitic stainless steel (AM363) were chosen. AISI 301 is currently in use for revetment fabrics.

The bimetallic specimens consisted of zinc- and copper-clad low-carbon steel wires. The zinc-clad specimen was U.S. Steel Type C galvanized wire. The copper-clad wire was made by the Copperweld process and is currently in use for revetment fabrics.

The organic coatings tested were Coating Engineering Corporation's polyvinylchloride (PVC), Republic Steel's polyethylene, and Union Carbide's vinyl resin, VMCH.

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* Copperweld is a trademark of Copperweld Corporation.

[1] *Specifications for End Twist Wires (Wire Forms) and Straight Wires.* Solicitation No. DACW66-70-R-0050 (Corps of Engineers Memphis District, 1973).
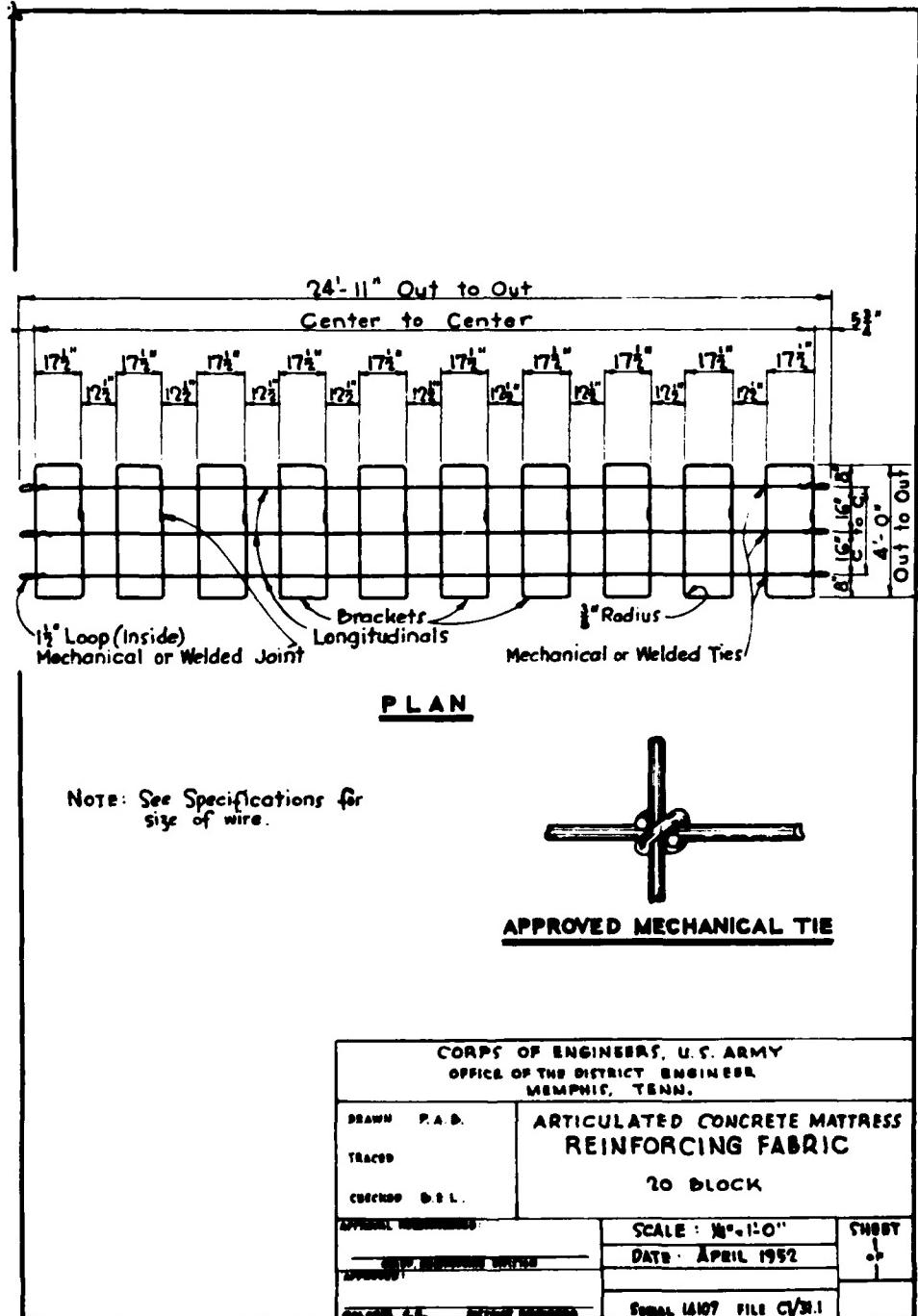
Figure 1. Articulated concrete mattress reinforcing fabric.
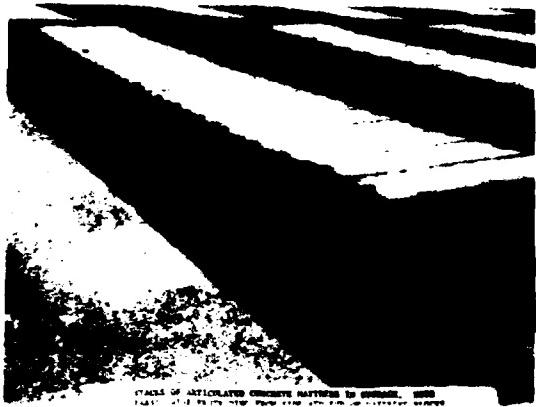
Figure 2. "Squares" after casting. The squares consist of concrete slabs cast onto the wire fabric.

The PVC and VMCH coatings are applied by dipping after fabrication; the polyethylene coating is extruded before fabrication.

Table 1 lists the materials and suppliers. Prices are shown in Table 2, and chemical compositions are given in Table 3.

The wire specimens were set into concrete as described in Table 4. The concrete was alkaline (pH 12) and may have been somewhat porous since no vibration was used during casting.

3 PROCEDURE

The first step in the investigation was to eliminate all candidate materials that did not meet the established mechanical properties specified for revetment fabrics (see the appendix).

Two wire segments, approximately 13 in. long, were cut from each material. One segment of each material was looped about itself at one end while the other was left straight. The VMCH organic coating was applied at CERL, while the PVC- and polyethylene-coated wires were procured already coated.

The wire specimens were then cast into concrete blocks, 6 in. x 6 in. x 36 in. The wires were embedded up to about one-half their length. The wires with looped ends were set so the loop was exposed to the water (Figure 4).

The blocks containing the wires were placed in racks (Figure 5) and lowered into the river at the two test points. To date the specimen blocks have been exposed for periods of 1, 3, 6, 12, 18, and 24 months; the 36-month exposure remains to be evaluated. Due to late arrival of some samples, the exposures did not all begin at the same time. The first group, consisting of carbon steel, AISI 301, Copperweld, AISI 430, galvanized steel, polyethylene-coated wire, PVC-coated wire, and VMCH-coated wire, began exposure in May 1972. The second group, containing carbon steel, AISI 301, Copperweld, AISI 201, Armco 18-2, and AM363 began exposure in November 1972. Table 5 gives the date of immersion and length of exposure for each specimen block.

After exposure for the desired time, the specimen blocks were removed and sent to CERL for evaluation. Corrosion resistance was first evaluated by macroscopically examining the condition of the wires just after removal from the water. At CERL the remaining silt and organic matter were removed, and the wires were examined for large pits, crevices, or areas of localized attack. The coatings were also checked for abrasion, cross-sectional attack, and general deterioration.

The wires were then removed from the concrete blocks for further examination. The entire length of each wire was fully examined at a low magnification (10x) for pits anywhere along the length, crevice attack in the loop-ended specimens, preferential attack where the wire specimen entered the concrete or at the severed ends, and formation of corrosion products at the severed ends of the bimetallic and organically coated wires. In addition, the organic coatings were checked for porosity and resistance to splitting where corrosion products had accumulated.

Specimens with peculiar appearances, particularly the galvanized and carbon steel wires, were examined in the scanning electron microscope (SEM). A visual examination was also performed, primarily to discern the presence of large-scale corrosion and whether it occurred at a particular location. It was discovered that the looped-end specimens formed a stagnant layer conducive to crevice attack.

Where corrosion was observed, the specimens were sectioned for metallographic study. This technique was used extensively to assess the presence and rate of attack in the bimetallic wires.
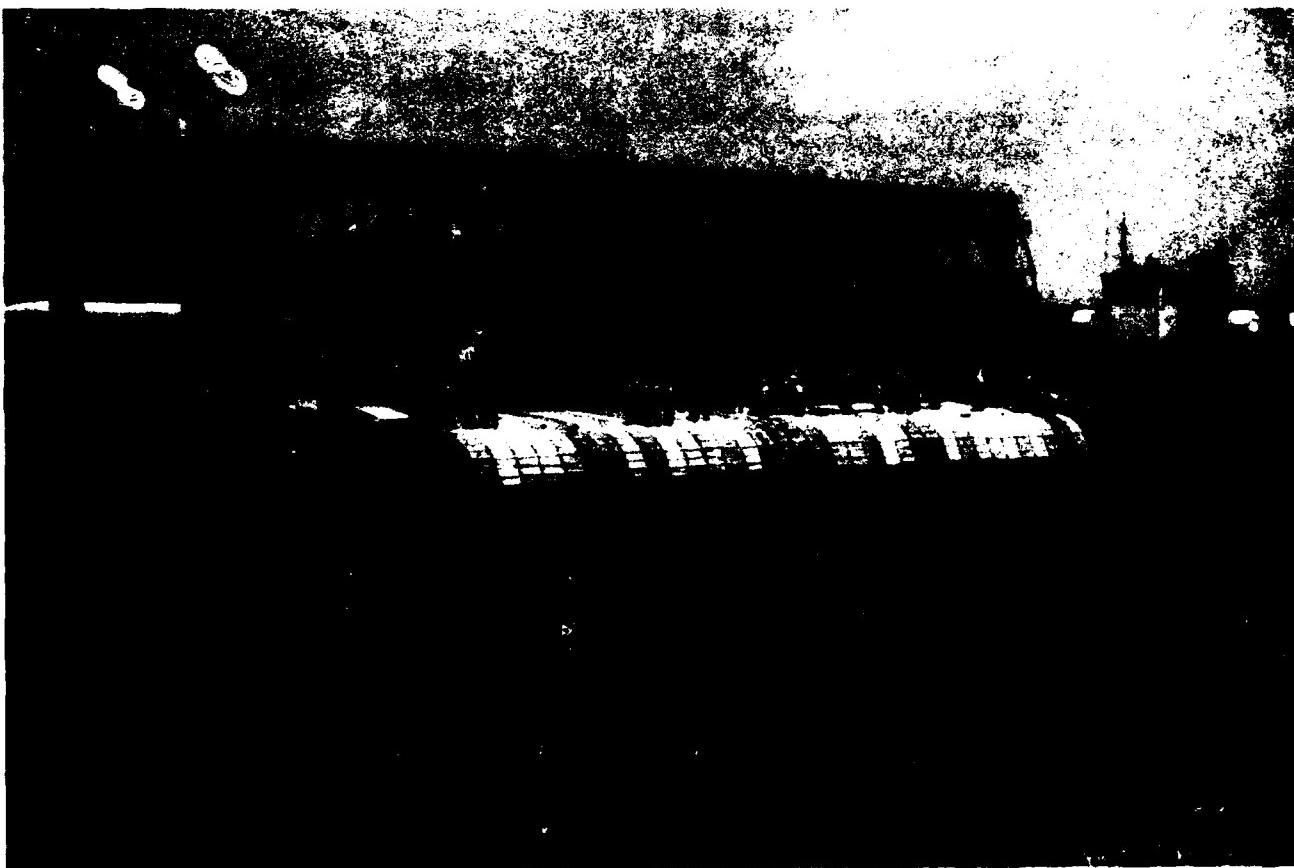
Figure 3. Articulated concrete mattress (after assembly) being launched.

Figure 4. Test block with looped-end test wires after exposure.
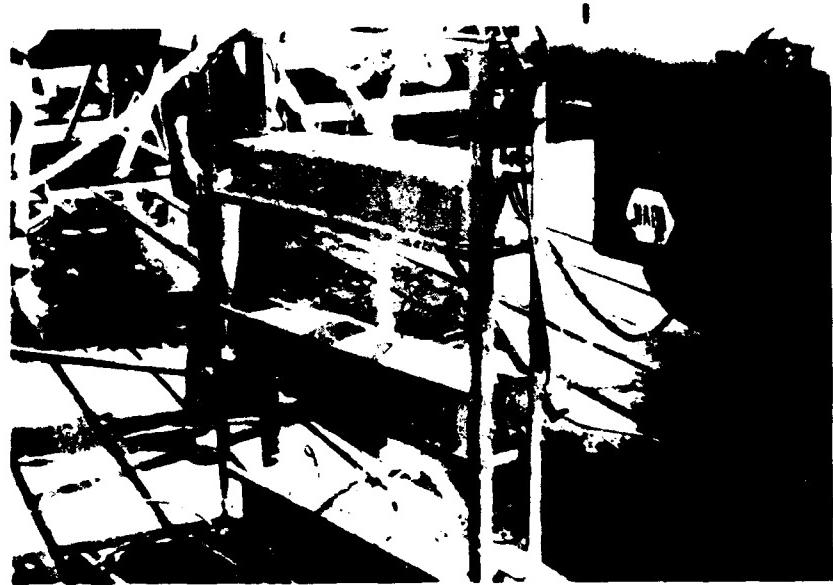
Figure 5. Exposure rack. Specimen blocks were inserted into the horizontal shelves, and the entire assembly was lowered into the river.

Measuring the change in resistance that occurred over a time interval was the second method used to determine the presence of corrosion. Resistance measurements have the advantages of simplicity of technique and reproducibility of results. Changes that arise from corrosion result from a change in the wire cross section. Both localized corrosion and uniform attack cause an increase in resistance. In general, corrosion products have a much higher electrical resistivity than do the metals on which they form and therefore do not interfere with resistance measurements.[2] The coatings were removed from the specimens coated with organic materials, and resistance was measured with a milliohm meter along a 4 in. length of wire which included the region of wire emerging from the concrete block. Resistance after exposure was then compared with resistance of unexposed wires.

The third method for determining if corrosion had occurred was measurement of changes in mechanical properties. This method is particularly important in the design of the structure if there is a time-related loss of strength of ductility. The method will reveal the presence of corrosion undetected by other measurements since corrosion anywhere along the length affects the mechanical properties, and failure always occurs at the weakest point. Mechanical properties also indicate the severity of corrosion since there is initially a decrease in ductility but little reduction in strength. As the corrosion process continues, the ductility remains low and the strength of the component starts to decrease.[3]

After macroscopic examination, one set of wires was tested in tension to failure. The presence of a yield point, the maximum load, the load at failure (if different), and the elongation at failure were measured. The fracture surfaces were then inspected and the location or the fracture noted. Data on reduction in area of the fracture surfaces were also obtained. The behavior of the coatings on the bimetallic and organically coated specimens during testing was also observed.

To evaluate whether the welded stainless steel wires were sensitized, the 65 percent boiling nitric acid test (ASTM Test A262-70 Practice C) was used. This quantitative test, which compares weight loss to surface area, indicates the susceptibility of the alloy to attack because of chromium carbide precipitation.

Sensitization of stainless steel is a form of intergranular corrosion caused by changes in the vicinity of the grain boundaries induced by precipitation of carbides or interstitials which occurs within specific temperature ranges. Significant dwell time in these temperature ranges may occur during cooling of the welded wire.

The standard test method consists of immersion of steel samples (weighted, cleaned, and dimensioned) in boiling reagent nitric acid (HNO_3) for five 48-hr periods with changes of fresh acid every period. (In this investigation a single 48-hr period was used for evaluation.) Acid solutions are placed in 1000-ml Erlenmeyer flasks with cold-finger condensers. After each period, samples are rinsed, ultrasonically cleaned in acetone, and weighed on an analytical balance.

Specimens tested consisted of weldments, as-received wire stock, and wire sensitized by laboratory heat treatment. The austenitic steels were sensitized at 750°C for 2 hrs and then water-quenched. The ferritic and martensitic stainless steels were sensitized for 1.5 hrs at 900°C and immediately water-quenched.

4 RESULTS AND DISCUSSION

Resistance measurements are given in Table 6 and mechanical property data in Tables 7 through 16.

Stainless Steel

Stainless steel seems to be an attractive material in terms of long-term corrosion resistance and ease of fabrication by conventional methods. The corrosion resistance of stainless steels has been attributed to the formation of an adherent, passive surface layer.[4] However, corrosion occurs whenever there is a breakdown in this passive film.

Pitting, the most common type of corrosion in stainless steels, generally occurs in high-chloride environments. Pitting is a self-initiated attack, characterized by severe localized corrosion. The susceptibility of stainless steel to pitting is reduced by the addition of nickel and molybdenum; the higher-nickel austenitic stainless steels are the most resistant.[5]

[2] I. A. Champion, *Corrosion Testing Procedures* (John Wiley and Sons, 1965), p 239.

[3] Champion, p 229.

[4] L. L. Shreir, *Corrosion*, Vol 1 (John Wiley and Sons, 1963), pp 3.55-3.57.

[5] H. H. Uhlig, *Corrosion and Corrosion Control* (John Wiley and Sons, 1963), pp 272-273.

Other types of corrosion that attack stainless steels include crevicing, stress corrosion, and intergranular corrosion after sensitization. Crevice attack generally occurs as a result of either oxygen depletion due to accumulation of organic material on the surface, or the presence of a stagnant environment induced by geometry. The loop-ended specimens were used in an attempt to form a stagnant layer in the region where the wire contacted itself. Stress corrosion cracking, which generally occurs in highly stressed components in an aggressive environment, has been found to be a problem with stainless steels in saltwater environments. Sensitization is a localized corrosion attack generally associated with the depletion of chromium in the heat-affected zone of a welded component. The areas adjacent to the grain boundaries are attacked, leading to a failure.

AISI 201

Corrosion data on AISI 201 stainless steel exposed to the Mississippi River have been obtained for 6- and 18-month exposures. Although the wires were heavily fouled with organic matter, macroscopic and microscopic examinations indicated no pitting, even on the ends. Examination of the looped specimens showed no indication of crevice attack.

No change in resistance occurred during these exposure intervals (Table 6).

During testing, this material did not exhibit a yield point and strain-hardened to failure; consequently, the tensile strength was equal to the failure strength (Table 7). In the exposed specimens, tensile strength did not decrease with exposure time. The reduction in area was about the same as for unexposed wire. Fracture generally occurred along the exposed section.

AISI 301

Corrosion data for this steel have been obtained for 1-, 3-, 6-, 12-, 18-, and 24-month exposures, including tests initiated in the spring and fall. The longer-term exposure samples were heavily encrusted with silt and organic matter. However, neither macro- nor microscopic examination revealed any pitting. No crevice attack was observed in the loop-ended specimens.

The resistance data (Table 6) indicate no significant change in resistance with time of exposure.

The tensile tests (Table 8) revealed that AISI 301 is a highly strain-rate-sensitive material in which ductility can be greatly increased at very low strain rates. AISI 301 did exhibit a yield point which exceeded its ability

to work-harden; consequently, the yield point was equivalent to the tensile strength while the fracture strength was somewhat lower. There was no change in reduction in area with time; the fracture locations were sufficiently random to preclude localized attack.

AM 363

AM 363, a proprietary alloy of Allegheny-Ludlum, was the only martensitic stainless steel considered. This material was included in the group of materials which began exposure in November 1972. The data gathered to date consist of 6- and 18-month exposures.

Neither pitting nor crevice attack were detected on the wire surface after exposure. Resistance (Table 6) did not change with time, confirming the visual inspection results.

The tensile test (Table 9) indicated no loss in tensile strength during the exposure although there may have been a slight reduction in ductility. Fracture occurred in the wires along the length embedded in concrete in the 6-month sample and at the water-concrete interface in the 18-month sample.

AISI 430

AISI 430, the only ferritic stainless steel alloy considered, has been exposed for periods of 1, 3, 6, 12, and 24 months to date.

Many of the specimen blocks containing this wire were heavily encrusted with silt and covered with organic matter from the river. Macroscopic examination showed the surfaces to be free of pitting and crevice attack for each exposure. This observation is supported by the resistance data for this material (Table 6) which shows no change in resistance after exposure.

The tensile tests performed on this material (Table 10) showed that it work-hardens to failure. Consequently, the breaking strength is equal to the tensile strength. No yield point was observed. The tensile strengths of the exposed specimens were lower than those of the unexposed wires. However, the consistency of both groups of data indicates that a mechanical strength difference may have existed along the length of the coil of wire. The decrease in strength has not been identified as the result of corrosion. No change in ductility or reduction in area occurred. Fracture occurred either along the length exposed to the water or at the concrete-water interface.

Armco 18-2

Armco 18-2 is a low-nickel, austenitic stainless

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steel. Since it began exposure in November 1972, data are available only for 6 and 18 months of exposure.

No surface deterioration in the form of either pitting or crevice attack was found on the wire surfaces. Resistance did not change with exposure time, indicating a lack of corrosion.

The tensile tests (Table 11) showed that this alloy has low ductility and essentially zero reduction in area, perhaps because the wire samples were heavily cold-worked, or because of their small diameters. The lack of ductility could result in the material failing the physical specifications.

There was no loss of tensile strength due to exposure, nor was there a decrease in ductility. No change in reduction in area as a function of exposure time was observed.

Bimetallic Specimens

Bimetallic materials are widely used where corrosion resistance is required. The bimetallics chosen for wire fabric materials are low carbon steel clad with either copper or zinc. The copper is used as a protective coating for the steel. Due to a difference in electrochemical potential, however, this combination can cause rapid corrosion where the underlying steel is exposed. The zinc coating inhibits corrosion in two ways: by protecting the surface of the steel, and by corroding sacrificially, thereby cathodically protecting the steel surface. In this part of the investigation, corrosion of the bimetallic materials was compared to corrosion of uncoated low carbon steel.

Low Carbon Steel

Plain carbon steel wire was tested solely as a standard for comparison purposes, not as a candidate wire fabric material.

Corrosion of the carbon steel occurred after a short exposure time. Microscopic examination of specimens exposed for 1 month revealed the presence of rust along the length exposed to the water. After longer time periods, the rust was more prominent, and accelerated attack was observed at the region where the wire emerged from the concrete. The accelerated attack resulted in the formation of a necked region (Figure 6). It was estimated that this necked region could be completely corroded away in approximately 2 years. High-magnification examination of the necked region revealed that the corrosion occurred in layers oriented along the length of the wire. An SEM photograph of this region is shown in Figure 7. In contrast to the

rapid attack that occurred along the length exposed to the water, no corrosion was observed along the section embedded in concrete. This was attributed to the alkalinity of the concrete.[6]

Resistance measurements made on the plain carbon steel wires showed little change in the first 3 months. After 18 months of exposure, however, resistance had doubled. The resistance increased rapidly as the wires necked, becoming infinite in wires which had corroded completely through.

The tensile tests (Table 12) showed that the material exhibited a definite yield point, and work-hardened to the point of fracture. The load-carrying capacity decreased rapidly for exposure times greater than 12 months and decreased to zero in about 2 years as a result of being corroded completely through. A similar loss in ductility occurred; after 18 months of exposure, the ductility had decreased from about 5.6 percent to 1.8 percent, and from 18 to 24 months it approached zero.

Galvanized Low Carbon Steel

The material evaluated was U.S. Steel's Type C galvanized steel wire intended for severe conditions. None of the galvanized wires survived the wrap test (see the appendix) with their zinc coatings intact. This cracking of the zinc coating accelerates the corrosion rate of the zinc. The steel remains protected as long as the zinc is present, since the zinc corrodes sacrificially.

At high magnifications there appeared to be deep pits, especially in the region where the wire emerged from the concrete; Figure 8 shows this section of a wire exposed for 1 year. Pitting of the zinc surface layer was also found in unexposed wires. Figure 9 is a low-magnification photograph of unexposed wire; a high-magnification photograph of one of the pits is shown in Figure 10. It is believed that in some instances these pits extend to the surface of the carbon steel wire. Examination of the zinc surface layer after exposure indicated that the pits initially present will deepen and open until the zinc surface layer becomes insufficient to inhibit corrosion of the exposed steel. The projected life of the galvanized wire is approximately 8 to 10 years.

The resistance measurements (Table 6) showed a slow increase with exposure time due to a loss (dissolution) of the zinc from the surface.

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[6]H. H. Uhlig, *Corrosion and Corrosion Control* (John Wiley and Sons, 1963), pp 85-92.

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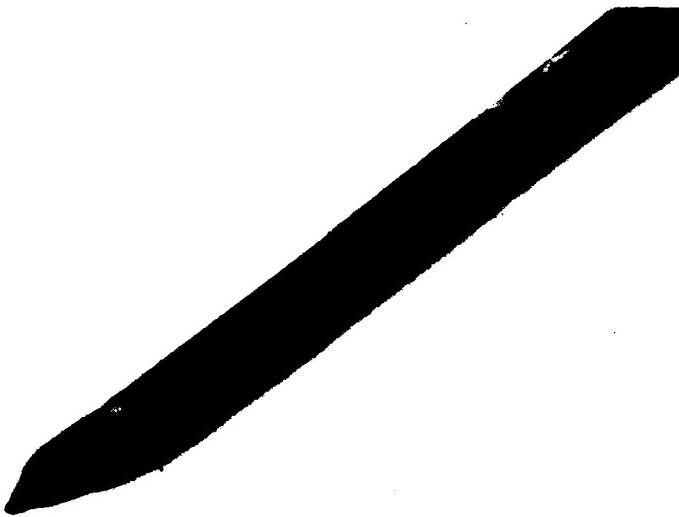
Figure 6. Macrograph of accelerated corrosion in plain carbon steel wire at the region where the wire exits from the concrete. (2x)
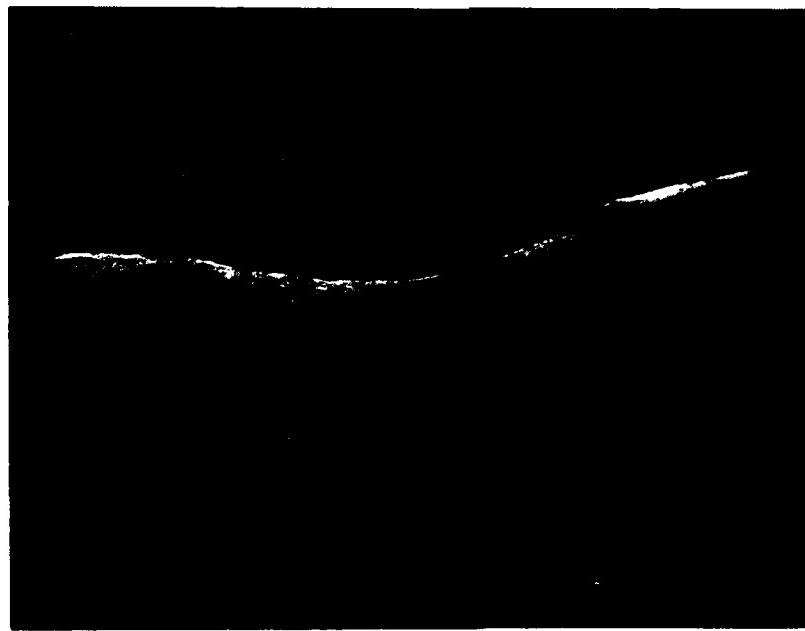
Figure 7. SEM photograph of the accelerated corrosion region in plain carbon steel wire. Note the geometry of attack, the layered corrosion region, and the apparent attack at the grain boundaries.

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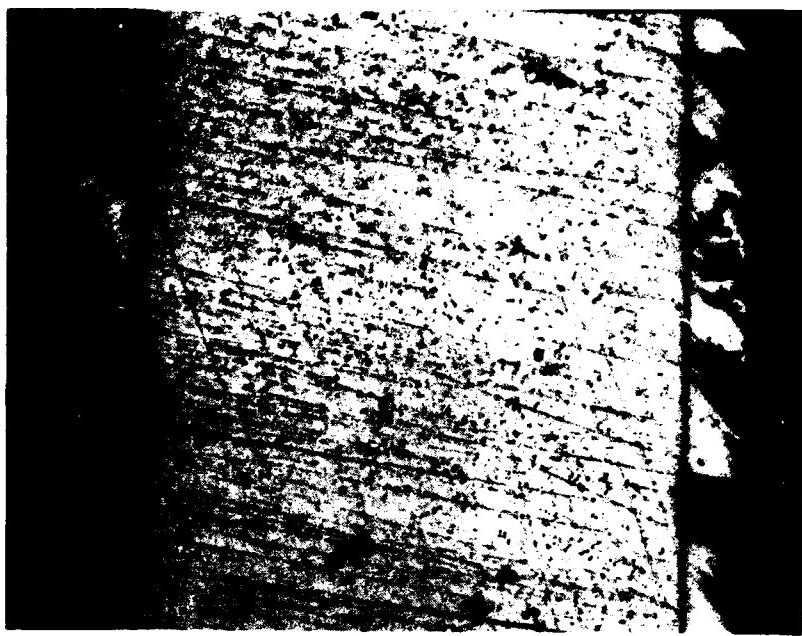
Figure 8. Micrograph of galvanized wire after exposure for 1 year. Note the presence of deep pits in the zinc outer layer which penetrate to the surface of the steel. (50x)
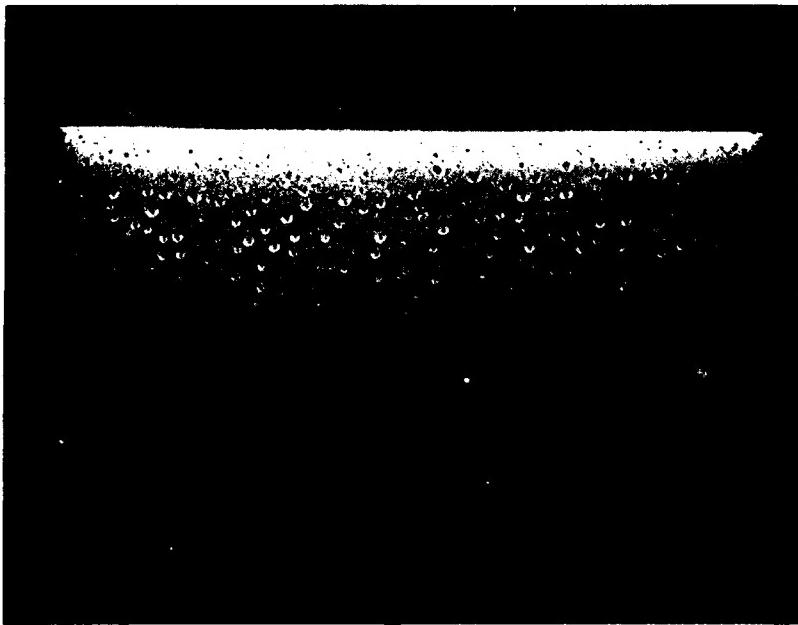
Figure 9. SEM micrograph of unexposed galvanized wire surface. This shows that the zinc outer layer is pitted prior to exposure.
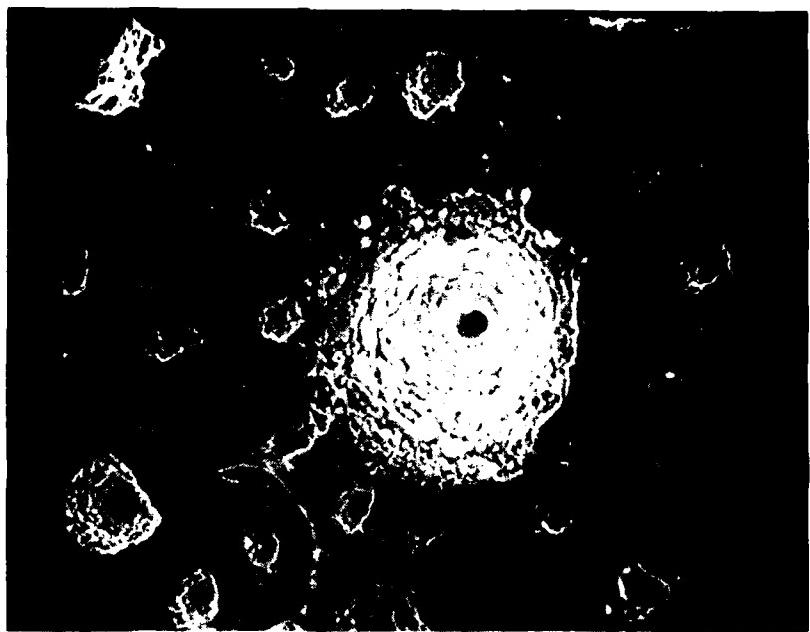
Figure 10. High-magnification SEM micrograph of pits (pores) in the zinc surface.
(500x)

Figure 11. Micrograph of the exposed end of copper-clad steel wire after exposure. Note the porous steel core and the attack on the inside of the copper cladding.

(55x)

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Data for the tensile tests (Table 13) indicate no loss of tensile strength with time and no decrease in ductility. Although tensile strength, ductility, and reduction in area did not change, there may have been a mild, localized attack at the region where the wire emerged from the concrete, since tensile fractures occurred predominantly at the interface. Earlier tests[7] have shown that very little deterioration occurs after 2 years when the zinc wires are covered with silt, but that without the protective silt covering, they will corrode extensively after 2 years of exposure to the Mississippi River.

Copperweld Steel

The copper-clad steel used in the investigation consisted of tie wires of the type currently used in revetments. The copper coating is applied using the Copperweld process, which makes the copper adhere well to the steel. The steel is protected as long as the coating is intact; however, a rupture in the coating causes acceleration of the corrosion process because the steel cathodically protects the copper. Seizing or rupturing of the copper coating has been found to be a rare occurrence, however, since the copper flows easily along the carbon steel.

Examination of the surfaces after exposure revealed very little deterioration anywhere along the length. No pits were found in the straight wires, nor were crevices found in the looped-end specimens. Rapid corrosion was observed at the ends where the steel core was exposed (Figure 11). The depth of corrosion into the wire was measured (Table 17) plotted versus time (Figure 12). The specimens initially exposed in November appear to have a higher corrosion rate. From the data, it appears that a rupture in the copper cladding would lead to corrosion completely through the steel core in approximately 6 months.

The resistance measurements of the exposed wires (Table 6) showed an increase in resistance with respect to time of exposure. The cause of the increase is believed to be a uniform loss in coating thickness.

The mechanical property tests on the copper-clad wire (Table 14) showed no loss in strength with time. Reduction in area did not change appreciably with time of exposure, and tensile fractures occurred at random locations along the wire.

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[7]*Report on Corrosion Test of Metals in the Mississippi River* (Corps of Engineers Memphis District, May 1939).

Organic Coatings

Use of organic coatings to cover steel wire is a good method of producing a high-strength, corrosion-resistant product. Of particular interest are the polymer coatings, which are impervious to electrochemical corrosion, do not deteriorate, and generally do not react with the product they coat. However, for organic coatings to be practical for fabrication of wire fabrics, they must:

1. Inhibit corrosion of steel wire in the Mississippi River
2. Be easily applied
3. Be easily fabricated
4. Be nonporous
5. Have good adherence to steel
6. Meet physical requirements
7. Be durable
8. Be economical in terms of initial cost and application.

Most of the organic coatings available meet these criteria except for adherence and the physical requirements stated in the appendix. Three coatings which could possibly meet the above requirements were found - polyvinylchloride (PVC), polyethylene, and VMCH (a proprietary coating of Union Carbide Company).

Polyvinylchloride

The PVC-coated wire specimens were obtained from Coating Engineering Corporation. PVC coating is generally applied by dipping the component into the liquid PVC and letting the amount that adheres dry on the surface. After curing (drying), the coating is ready for use. The exposure specimens consisted of rectangular sections cut from mesh, with the severed ends left open to expose the steel. The average thickness of the coating for the specimens evaluated ranged from 0.010 to 0.013 in. The coating was generally nonuniform; the top surface was thinner than the bottom. In some instances, large drips were present. The coating quality was adequate.

Examination of the specimen surfaces after exposure revealed some porosity in the coating, which was probably present when the coating was applied. The porosity did not extend through the coating to the steel wire. Examination of the exposed end showed rust accumulation; after 18 months the volume expansion of the corrosion product was sufficient to split the coating. Removal of the coating from the steel
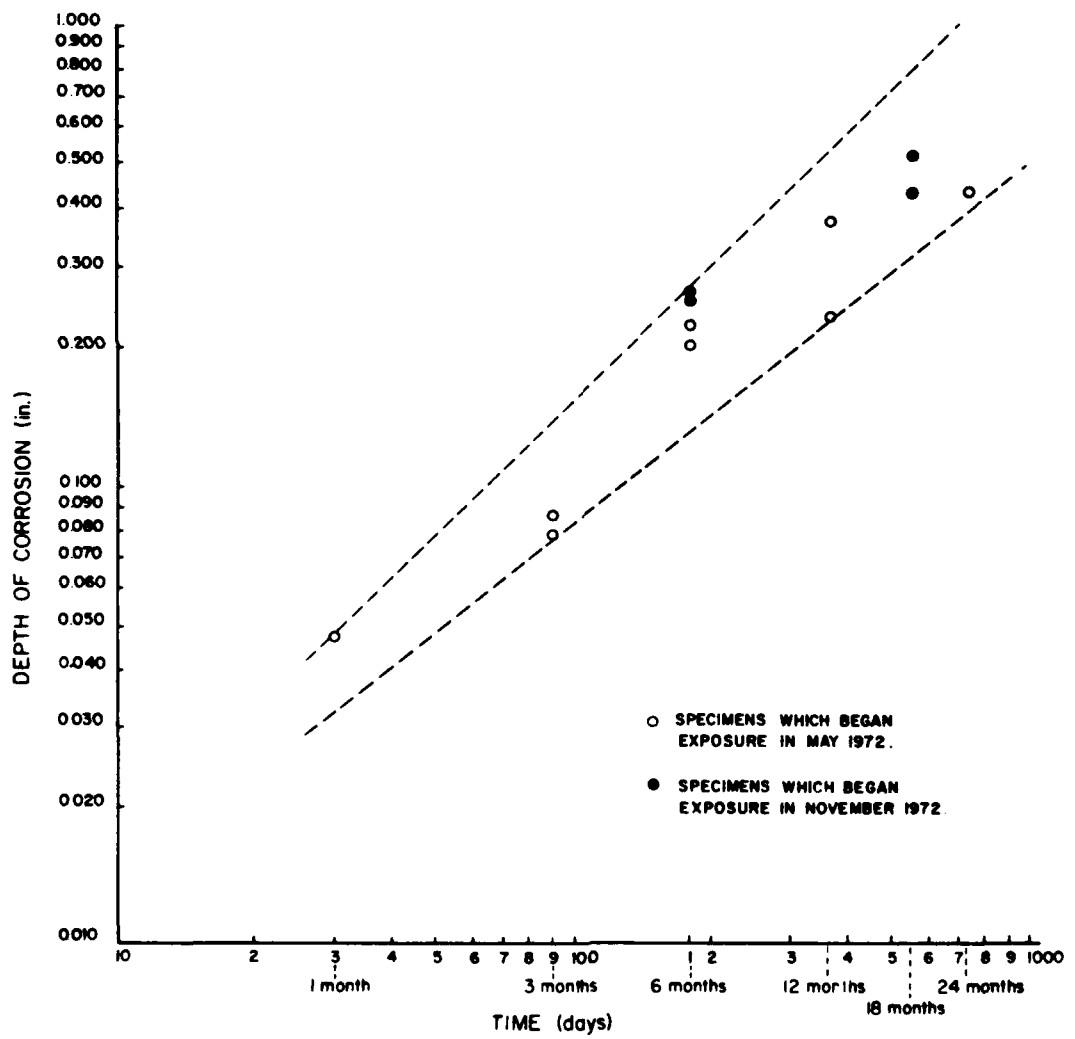
Figure 12. Depth of corrosion in copper-clad steel wiring.

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underwire revealed rust on the steel near the exposed ends, due to water seeping under the coating. The quantity of rust under the coating does not yet appear to be a detriment to use of this coating.

The resistance of the wires did not change with time. The tensile tests (Table 15) indicated that no loss of strength or ductility occurred. There was no change in reduction in area, and the location of the tensile fractures was random.

Polyethylene

The wire samples used for evaluation were obtained from Republic Steel Co. and were fabricated using their special process. Preparation of the coated wire consisted of abrading the steel wire surface, applying a mastic undercoating, and extruding a polyethylene outer coating over this. The thickness of the coating was nominally 0.028 in. and was extremely uniform. The quality of the coating was excellent. A disadvantage of this coating is that because the polyethylene must be extruded onto the steel wire, fabrication must follow application of the coating.

Evaluation of the wire specimens after exposure revealed large amounts of rust at the end where the steel wire was exposed. This accumulation has not yet been sufficient to cause the coating to split. Examination of the surface of the coating showed no deterioration. When the coatings were removed from the specimens, the wire beneath was free of corrosion, and, for the exposures to date, there was little penetration of rust into the wire. The mastic undercoating was intact in all cases, and no seepage under the polyethylene was found. The resistance data accumulated to date show no change with exposure time.

The results of the tensile tests (Table 16) showed no change in tensile strength or ductility for any of the exposed specimens. No change in reduction in areas with exposure time was evident, and the tensile fractures tended to occur predominantly along the length exposed to water.

Problems were experienced in preparing the polyethylene-coated wires for field testing. The wires were cast into five rectangles (25 ft x 4 ft) to be sunk into the Mississippi River. After the concrete had cured at the casting yard, the squares were transferred by barge to the assembly area where they were to be connected to other squares to form mattresses. The squares were placed on the barge using a rectangular frame connected to a crane. The frame, which has an outcrop of 20

fingers, fits over a stack of 13 squares and lifts them simultaneously by their outside wires. During the transfer, it was noticed that the fingers did not grab each square individually, but transferred most of the weight to the wires in the bottom four squares. At the end of this operation a number of gashes (one of them about 3 in. long) were observed in the coating, exposing the bare metal. When the squares were at the assembly area, their end loops were tied together by hand while the longitudinal wires were tied to a launching cable by a pneumatic tying tool. After tying had been completed, more breaks in the coating were found. As a result of these breaks, the polyethylene-coated wire was judged unsuitable for use in revetment operations.

VMCH

VMCH, a product of Union Carbide, is a transparent dip coating similar to PVC. The coating thickness ranged from 0.006 to 0.008 in. and was very uniform. However, examination of the coatings revealed the presence of entrained air bubbles in the coating. The coating, although apparently brittle, survived the tensile tests.

After exposure, the coating was found to be porous in some spots; water seepage had occurred in these regions. Specimens evaluated after 18 months of exposure exhibited cracks in the coating and corrosion underneath. The coating may have degraded as a result of being applied too thinly, or it may have been scratched during specimen preparation. Due to this rapid deterioration, evaluation was not continued after the 18-month exposure.

Sensitization Tests

The Huey (boiling nitric acid) sensitization test was conducted on both the as-received and as-welded stainless steel alloys.

Stainless steel wires were welded using various heat inputs and numbers of cycles. To insure compositional uniformity, as-received sections were taken from the welded wires away from the welded region. In addition, some wires were intentionally sensitized for comparison. All specimens were tested separately. Corrosion rates were calculated using the formula:

$$\frac{mils}{yr} = 82.77 \frac{W}{DAt}$$

where

W = weight loss, mg
D = density of alloy

20

A = area sq cm

t = time, hr (48 hr/boiling period)

These data are summarized in Table 18.

The corrosion rates of the sensitized samples were all higher than the as-received samples, except for alloy AM-363. This alloy has a higher corrosion rate than the others because it has only about 12 percent chromium and is a martensitic microstructure. The corrosion rates of the welded sections were slightly greater than for the as-received specimens of the same alloys, particularly in alloys 18-2 and AISI 201. On the other hand, little difference between the as-received and as-welded corrosion rates was found for alloys AISI 301 and AISI 430.

The sensitization data were based solely on surface corrosion and may not reflect the lifetime corrosion rate. Since these were only screening tests and were much more severe than Mississippi River waters, the results obtained are indicative only of relative sensitization resistance. The actual corrosion resistance of these alloys in fresh water can only be inferred from the results. However, the results do indicate that sensitization is not anticipated to be a problem in fresh water above New Orleans.

5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The susceptibility of stainless steel, bimetallics, and organically coated steel to corrosion in the Mississippi River above New Orleans is presently being evaluated. As a result of the analysis of specimens after 1½ to 2 years of exposure, it is concluded that:

1. All the stainless steels have more than enough strength and corrosion resistance in the Mississippi River above New Orleans to qualify them as substitute mattress materials. The only stainless steel which may be questionable as a fabric material is Armco 18-2, which met the corrosion resistance requirements but had very low ductility.

2. The bimetallic materials evaluated performed satisfactorily with respect to corrosion resistance. However, silt covering enhanced the corrosion resistance of some of these materials. Also, problems encountered

during machine handling of these materials may cause a major change in the expected life of the component. The galvanized wire appears to be especially susceptible as a result of inadequate adherence of the zinc to steel when the combination is mechanically deformed (i.e., bending the wire). Since the worst treatment of the wire fabrics results from bending during handling in the casting yard, assembling into revetments, and launching, this could be a cause for rejection.

3. All the organic coatings evaluated in this investigation passed the tensile requirements for wire mattress fabrics, although the polyethylene-coated wire failed the field tests. Except for VMCH, all of the coatings provide adequate corrosion resistance for carbon steel wire in the Mississippi River.

4. Judgment of the polyvinylchloride-coated wires will be deferred until the 2-year exposure samples have been analyzed.

Recommendations

The following recommendations are based on the results and conclusions of this investigation:

1. A number of squares should be fabricated from AISI 201, AISI 430, AM 363, and 18-2 stainless steel alloys and field tested.

2. Exposure tests at or below New Orleans should be conducted on welded stainless steel wires to ascertain what degree of sensitization would be detrimental to the use of welded fabrics in this area of the Mississippi River.

3. If the stainless steel squares perform satisfactorily in the field, the specification pertaining to the type of fabric material (Part II, Sect. 1-02) should be expanded to include all of the stainless steels examined in this study.

4. Modifications that would be required in the handling equipment in order to use the organically coated fabrics should be determined and whether these modifications would be cost-effective when used in conjunction with organic coatings should be ascertained.

5. The zinc-coated wire should be considered unacceptable as a substitute fabric material.

6. The polyethylene-coated wire should be considered unacceptable as a substitute fabric material.

Table 1
Materials and Suppliers

Material	Supplier
Carbon Steel	U.S. Steel
Galvanized Type C Steel	U.S. Steel
Copperweld Steel	Copperweld
Type 201 Stainless Steel	Allegheny-Ludlum
Type 301 Stainless Steel	Central Steel and Wire Co.
Type 430 Stainless Steel	Central Steel and Wire Co.
Type 18-2 Stainless Steel	Armco Steel
AM 363 Stainless Steel	Allegheny-Ludlum
VMCH-Coated Steel	Union Carbide Corp.
Polyethylene-Coated Steel	Republic Steel
Polyvinylchloride-Coated Steel	Coating Engineering Corp.

Table 2
Wire Cost per Pound*

	Producer							
	Allegheny Ludlum**		Copperweld Corp.†		Armco†		U.S. Steel	
	Wire	Diameter	Wire	Diameter	Wire	Diameter	Wire	Diameter
Item	0.141ϕ ($/#)	0.160ϕ ($/#)	0.141ϕ ($/#)	0.160ϕ ($/#)	0.141ϕ ($/#)	0.160ϕ ($/#)	0.141ϕ ($/#)	0.160ϕ ($/#)
AISI 201	$1.36-3/4	$1.28-3/4	–	–	–	–	–	–
AISI 301	1.36-3/4	1.28-3/4	–	–	–	–	$1.18	$1.15
AISI 430	1.22-1/2	1.09-1/2	–	–	1.18	1.05	1.02	0.99
AM 363	1.46	1.38	–	–	–	–	–	–
Armco 18-2	–	–	–	–	1.13	1.19	–	–
Copper-Clad	–	–	$0.830	$0.824	–	–	–	–
Galvanized (1018)	–	–	–	–	–	–	0.22-1/4	0.22-1/4
Carbon Steel (1018)	–	–	–	–	–	–	0.17-1/4	0.17-1/4

Polyethylene-Coated Steel: no longer produced by Republic Steel
Polyvinylchloride-Coated Steel: not available at this time

* Prices are as of April 1975.
** All prices FOB Dunkirk, PA; minimum order 10,000 lb; $0.02 wrapping and packaging.
† 30,000-lb base, plus 5% for smaller orders, packaging additional.

Table 3
Typical Chemical Compositions of Stainless Steel Test Specimens

Specimen	Carbon (C)	Chromium (Cr)	Nickel (Ni)	Manganese (Mn)	Phosphorus (P)	Sulfur (S)	Silicon (Si)	Nitrogen (N)	Other
AISI 301	0.15	16.0-18.0	6.0-8.0	2.0	0.045	0.030	1.0		
AISI 201	0.15	16.0-18.0	3.5-5.5	5.5-7.5	0.060	0.030	1.0	0.25	
Armco 18-2	0.10	18.0	1.6	12.0			0.50	0.34	
AM 363	0.04	11.5	4.5						0.50 Titanium
AISI 430	0.12	15.0-18.0		1.0	0.040	0.030	1.0		

Table 4
Composition of Revetment Concrete

Material		Batch Weight, lb	Percent
I. Proportions			
	Portland Cement	139.8	8.35
	Fine Aggregate	558.9	53.38
	Coarse Aggregate	872.4	52.11
	Water	103.1	6.16
	TOTAL	1674.2	100.00
II. Mixture Data			
	Ambient Temperature	72°F	
	Concrete Temperature	72°F	
	Sand/Aggregate Ratio	3.8 Vol %	
	Water/Cement Ratio	0.74 Weight %	
	pH	12	

Table 5
Summary of Exposure Test Parameters

Block Number	Began Exposure	Ended Exposure	Length of Exposure (mon)	Specimen Group*	Type of Specimens
1	lost in 73 spring flood at Delta Point			A	Straight
2	in storage—New Orleans			A	Straight
3	lost in 73 spring flood at Delta Point			A	Straight
4	in storage – New Orleans			A	Looped
5	in storage Waterways Experiment Station (WES)			A	Looped
6	in storage WES			A	Looped
7	May 72	Aug 72	3	A	Straight
8	May 72	May 74	24	A	Straight
9	May 72	Nov 72	6	A	Straight
10	May 72	Aug 72	3	A	Looped
11	May 72	May 75	36	A	Looped
12	May 72			A	Looped
13	in storage CERL			A	Looped
14	lost in 73 spring flood at Delta Point			A	Looped
15	May 73			A	Looped
16	May 73			A	Looped
17	lost in 73 spring flood at Delta Point			A	Looped
18	lost in 73 spring flood at Delta Point			A	Looped
19	May 72	June 72	1	A	Looped
20	May 72	May 73	12	A	Looped
21	May 72	May 74	24	A	Looped
22	May 72	May 73	12	A	Straight
23	May 72	Nov 72	6	A	Straight
24	May 72	June 72	1	A	Straight
25	lost in 73 spring flood at Delta Point			B	Looped
26	lost in 73 spring flood at Delta Point			B	Looped
27	lost in 73 spring flood at Delta Point			B	Looped
28	Nov 72	May 75	30	B	Looped
29	Nov 72	May 74	18	B	Looped
30	Nov 72			B	Looped

Table 5 (cont'd)

Block Number	Began Exposure	Ended Exposure	Length of Exposure (mon)	Specimen Group*	Type of Specimens
31	in storage - CERL			B	Looped
32	May 73			B	Looped
33	May 73			B	Looped
34	lost in 73 spring flood at Delta Point			B	Straight
35	lost in 73 spring flood at Delta Point			B	Straight
36	lost in 73 spring flood at Delta Point			B	Straight
37	Nov 72	May 73	6	B	Straight
38	Nov 72	May 73	6	B	Straight
39	Nov 72	May 74	18	B	Straight
40	in storage - WES			B	Straight
41	in storage - WES			B	Straight
42	in storage - WES			B	Straight
43	in storage - WES			C	Straight
44	in storage - WES			C	Straight
45	in storage - WES			C	Straight
46	in storage - New Orleans			C	Straight
47	in storage - New Orleans			C	Straight
48	in storage - New Orleans			C	Straight
49	in storage - WES			C	Straight
50	in storage - WES			C	Straight
51A	in storage - WES			C	Straight
52A	in storage - WES			C	Straight
W-1	in storage - WES			D	Straight
W-2	in storage - WES			D	Straight
W-3	in storage - WES			D	Straight

* Wire specimens were separated into two groups, arranged in the following order:

    A.   Plain C, Cu Weld, 301, 430, Gal, Republic, Union Carbide, CFC

    B.   Plain C, Cu Weld, 301, 201, 18-2, 363

Welded wire specimens were separated into two groups, arranged in the following order:

    C.   Plain C, Cu Weld, 301, 201, 18-2, 363, 430, Gal, Republic, CFC

    D.   18-2, 301, 201, 36, 430 spot welded

Table 6

Resistance Data for Exposed Wires*

	Resistance Before Exposure mΩ	Resistance After Exposure**					
Material		1 Mon mΩ	3 Mon mΩ	6 Mon mΩ	12 Mon mΩ	18 Mon mΩ	24 Mon mΩ
Carbon Steel	1.60	1.65	1.65	NA	NA	3.30	∞
Copper Clad	0.66	0.68	0.70	0.70	NA	0.72	0.76
AISI 301	6.05	6.00	6.00	5.90	5.80	5.95	5.95
AISI 430	2.85	2.85	2.85	2.70	NA		2.80
Galvanized	2.25	2.54	2.40	2.40	NA		2.71
Polyethylene	1.70	1.75	1.75		NA		NA
VMCH		1.62	1.60		NA		NA
Polyvinylchloride	7.60	7.10	7.10	7.40	7.30		7.30
Armco 18-2	14.50			14.50		14.50	
AM 363	3.00			2.95		2.95	
AISI 201	4.40			4.40		4.40	

 * Resistance was measured along a 4.0-in. length; the concrete-water interface was normally located at the midpoint.

** Resistance data were not obtained for all specimens.

Table 7
Tensile Test Data - AISI 201 Stainless Steel Wire*

I. Unexposed Standard Specimen	Breaking Load (Strength)	Maximum Load (Strength)	Reduction in Area (%)	Elongation (%)
1	4525 lb (178 ksi)	4525 lb (178 ksi)	34	32
2	4480 (176 ksi)	4550 (179 ksi)	33	36
3	4510 (177 ksi)	4600 (181 ksi)	37	26
4	4500 (177 ksi)	4600 (181 ksi)	38	31
Average	4504 (177 ksi)	4569 (180 ksi)	35.5	31.2

	Exposure Time	Maximum Load (Strength)	R_1**	Failure Location	RA (%)
II.	6 Mon (Block 38)	4475 lb (176 ksi)	0.98	Water	33.3
III.	1½ Yr (Block 39)	4570 lb (180 ksi)	1.00	Water	37.6

*0.180 in. diameter
 0.025 sq in. cross-section
**Ratio of strength of exposed specimens to average strength of unexposed standards.

Table 8
Tensile Test Data – AISI 301 Stainless Steel Wire*

I. Unexposed Standard Specimen	Breaking Load (Strength)	Maximum Load (Strength)	Reduction in Area (%)	Elongation (%)
1	4050 lb (194 ksi)	4180 lb (200 ksi)	36.0	5.8
2	4000 (192 ksi)	4120 (197 ksi)	36.0	5.0
3	3950 (189 ksi)	4075 (195 ksi)	34.0	5.0
4	3975 (190 ksi)	4075 (195 ksi)	37.0	5.0
Average	3993 (191 ksi)	4112 (197 ksi)	35.7	5.2

	Exposure Time	Maximum Load (Strength)	R_1**	Failure Location	RA (%)
II.	1 Mon (Block 19)	4000 lb (192 ksi)	0.97	Water	35.6
III.	3 Mon (Block 7)	3900 (187 ksi)	0.95	Water	36.2
IV.	6 Mon (Block 9)	3900 (187 ksi)	0.95	Concrete	36.2
	(Block 38)	4200 (201 ksi)	1.02	Water	19.6
V.	12 Mon (Block 22)	4175 (200 ksi)	1.02	Concrete	35.0
VI.	18 Mon (Block 39)	4160 (199 ksi)	1.01	Concrete	34.8
VII.	24 Mon (Block 8)	4050 (194 ksi)	0.98	Concrete/Water Interface	37.7

*0.163 in. diameter
 0.021 sq in. cross section
**Ratio of strength of exposed specimens to average strength of unexposed standards.

Table 9
Tensile Test Data—AM 363 Stainless Steel Wire*

I. Unexposed Standard Specimen	Breaking Load (Strength)	Maximum Load (Strength)	Reduction in Area (%)	Elongation (%)
1	4600 lb (124 ksi)	4600 lb (124 ksi)	49.3	5.2
2	4600 (124 ksi)	4600 (124 ksi)	51.6	5.1
3	4600 (124 ksi)	4600 (124 ksi)	48.8	4.8
4	4600 (124 ksi)	4600 (124 ksi)	49.8	5.4
Average	4600 (124 ksi)	4600 (124 ksi)	49.8	5.1

	Exposure Time	Maximum Load (Strength)	R_1**	Failure Location	RA (%)
II.	6 Mon (Block 33)	4575 lb (124 ksi)	0.99	Concrete	45.2
III.	18 Mon (Block 39)	4520 (122 ksi)	0.98	Concrete/Water Interface	49.3

*0.217 in. diameter
0.037 sq in. cross section
**Ratio of strength of exposed specimens to average strength of unexposed standards.

Table 10
Tensile Test Data—AISI 430 Stainless Steel Wire*

I. Unexposed Standard Specimen	Breaking Load (Strength)	Maximum Load (Strength)	Reduction in Area (%)	Elongation (%)
1	4300 lb (137 ksi)	4300 lb (137 ksi)	32	4.9
2	4360 (139 ksi)	4360 (139 ksi)	32	4.6
3	4370 (139 ksi)	4370 (139 ksi)	30	4.8
4	4420 (141 ksi)	4420 (141 ksi)	31	4.8
Average	4362 (139 ksi)	4362 (139 ksi)	31.2	4.8

	Exposure Time	Maximum Load (Strength)	R_1**	Failure Location	RA (%)
II.	1 Mon (Block 19)	4100 lb (131 ksi)	0.94	NA	29.5
III.	3 Mon (Block 7)	4200 (134 ksi)	0.96	Water	25.0
IV.	6 Mon (Block 9)	4250 (135 ksi)	0.97	Water	30.5
V.	12 Mon (Block 22)	4275 (136 ksi)	0.98	Concrete/Water Interface	31.5
VI.	24 Mon (Block 8)	4180 (133 ksi)	0.96	Concrete/Water Interface	28.9

*0.200 in diameter
0.031 sq in. cross section
**Ratio of strength of exposed wires to average strength of unexposed standards.

Table 11
Tensile Test Data – Armco 18-2 Stainless Steel Wire*

I. Unexposed Standard Specimen	Breaking Load (Strength)	Maximum Load (Strength)	Reduction in Area (%)	Elongation (%)
1	2090 lb (265 ksi)	2090 lb (265 ksi)	0	2.5
2	2425 (309 ksi)	2425 (309 ksi)	0	3.0
3	2360 (300 ksi)	2360 (300 ksi)	0	2.9
4	2350 (299 ksi)	2350 (299 ksi)	0	3.0
Average	2306 (293 ksi)	2306 (293 ksi)	0	2.9

	Exposure Time	Maximum Load (Strength)	R_1**	Failure Location	RA (%)
II.	6 Mon (Block 38)	2400 lb (306 ksi)	1.04	Concrete	0.0
III.	18 Mon (Block 39)	2350 (299 ksi)	1.02	Water	0.0

*0.100 in. diameter
  0.008 sq in. cross section
**Ratio of strength of exposed specimens to average strength of unexposed standards.

Table 12
Tensile Test Data – Carbon Steel Wire*

I. Unexposed Standard Specimen	Breaking Load (Strength)	Maximum Load (Strength)	Reduction in Area (%)	Elongation (%)
1	4225 lb (205 ksi)	4225 lb (205 ksi)	23.5	5.4
2	4180 (203 ksi)	4180 (203 ksi)	18.5	5.5
3	4225 (205 ksi)	4225 (205 ksi)	19.0	6.3
4	4175 (203 ksi)	4175 (203 ksi)	19.0	5.3
Average	4201 (204 ksi)	4201 (204 ksi)	20.0	5.6

	Exposure Time	Maximum Load (Strength)	R_1**	Failure Location	RA (%)
II.	1 Mon (Block 19)	3950 lb (192 ksi)	0.94	Concrete/Water Interface	19.8
III.	3 Mon (Block 7)	3350 (168 ksi)	0.80	Concrete/Water Interface	26.5
IV.	6 Mon (Block 9)	3450 (167 ksi)	0.82	Water	26.5
	(Block 38)	3050 (148 ksi)	0.73	Water	29.6
V.	12 Mon (Block 20)	2675 (130 ksi)	0.64	Concrete/Water Interface	35.2
VI.	18 Mon (Block 39)	1580 (77 ksi)	0.38	Concrete/Water Interface	51.2
VII.	24 Mon (Block 8)	0 (0 ksi)	0.00	Concrete/Water Interface	0

*0.162 in. diameter
  0.021 sq in. cross section
**Ratio of strength of exposed specimens to average strength of unexposed standards.

Table 13

Tensile Test Data—Galvanized Wire*

I. Unexposed Standard Specimen	Breaking Load (Strength)	Maximum Load (Strength)	Reduction in Area (%)	Elongation (%)
1	1790 lb (158 ksi)	1790 lb (158 ksi)	18.3	10.2
2	1800 (159 ksi)	1800 (159 ksi)	18.8	8.5
3	1810 (160 ksi)	1810 (160 ksi)	17.5	10.9
Average	1800 (159 ksi)	1800 (159 ksi)	18.2	9.9

	Exposure Time	Maximum Load (Strength)	R_1**	Failure Location	RA (%)
II.	1 Mon (Block 19)	1800 lb (159 ksi)	1.00	Concrete/Water Interface	25.0
III.	3 Mon (Block 7)	1800 (159 ksi)	1.00	Concrete/Water Interface	22.5
IV.	6 Mon (Block 9)	1800 (159 ksi)	1.00	Concrete/Water Interface	6.7
V.	12 Mon (Block 22)	1800 (159 ksi)	1.00	Concrete/Water Interface	24.2
VI.	24 Mon (Block 8)	1830 (162 ksi)	1.02	Concrete/Water Interface	21.5

*0.120 in. diameter
0.011 sq in. cross section
**Ratio of strength of exposed specimens to average strength of unexposed standards.

Table 14
Tensile Test Data–Copper-Clad Steel Wire*

I. Unexposed Standard Specimen	Breaking Load (Strength)	Maximum Load (Strength)	Reduction in Area (%)	Elongation (%)
1	1440 lb (108 ksi)	1440 lb (108 ksi)	27.9	5.2
2	1440 (108 ksi)	1440 (108 ksi)	28.7	4.2
3	1440 (108 ksi)	1440 (108 ksi)	27.1	4.2
4	1430 (108 ksi)	1430 (108 ksi)	26.4	4.8
Average	1438 (108 ksi)	1438 (108 ksi)	27.5	4.6

	Exposure Time	Maximum Load (Strength)	R_1**	Failure Location	RA (%)
II.	1 Mon (Block 19)	1350 lb (102 ksi)	0.94	Concrete/Water Interface	30.0
III.	3 Mon (Block 7)	1400 (105 ksi)	0.97	Water	29.2
IV.	6 Mon (Block 9)	1450 (108 ksi)	1.01	Concrete	30.8
	(Block 38)	1400 (105 ksi)	0.97	Water	33.1
V.	12 Mon (Block 22)	1225 (92 ksi)	0.85	Concrete	32.3
VI.	18 Mon (Block 39)	1400 (105 ksi)	0.97	Concrete	25.6
VII.	24 Mon (Block 8)	1410 (105 ksi)	0.98	Water	27.9

*0.130 in. diameter
0.013 sq in. cross section
**Ratio of strength of exposed specimens to average strength of unexposed standards.

Table 15

Tensile Test Data—Polyvinylchloride-Coated Steel Wire*

I. Unexposed Standard Specimen	Breaking Load (Strength)	Maximum Load (Strength)	Reduction in Area (%)	Elongation (%)
1	340 lb (77 ksi)	340 lb (77 ksi)	34.7	7.8
2	310 (70 ksi)	310 (70 ksi)	45.3	7.7
3	340 (77 ksi)	340 (77 ksi)	52.0	7.5
4	343 (78 ksi)	343 (78 ksi)	49.3	6.5
Average	333 (75.5 ksi)	333 (75.5 ksi)	45.3	7.4

	Exposure Time	Maximum Load (Strength)	R_1**	Failure Location	RA (%)
II.	1 Mon (Block 19)	300 lb (68 ksi)	0.90	Concrete	37.3
III.	3 Mon (Block 7)	325 (74 ksi)	0.98	Concrete/Water Interface	26.7
IV.	6 Mon (Block 9)	350 (79 ksi)	1.05	Concrete	49.3
V.	12 Mon (Block 22)	350 (79 ksi)	1.05	Water	48.0
VI.	24 Mon (Block 8)	313 (71 ksi)	0.94	Water	51.6

*0.075 in. diameter
 0.004 sq in. cross section
**Ratio of strength of exposed specimens to average strength of unexposed standards.

Table 16

Tensile Test Data—Polyethylene-Coated Steel Wire*

I. Unexposed Standard Specimen	Breaking Load (Strength)	Maximum Load (Strength)	Reduction in Area (%)	Elongation (%)
1	4270 lb (210 ksi)	4270 lb (210 ksi)	24.8	5.4
2	4270 (210 ksi)	4270 (210 ksi)	22.5	4.9
3	4250 (209 ksi)	4250 (209 ksi)	36.0	5.1
4	4250 (209 ksi)	4250 (209 ksi)	24.2	4.7
Average	4260 (209.5 ksi)	4260 (209.5 ksi)	27.6	5.0

	Exposure Time	Maximum Load (Strength)	R_1**	Failure Location	RA (%)
II.	1 Mon (Block 19)	4200 lb (206 ksi)	0.99	Water	29.8
III.	3 Mon (Block 7)	4250 (209 ksi)	1.00	Water	29.2
IV.	6 Mon (Block 9)	4300 (211 ksi)	1.01	Water	28.0
V.	12 Mon (Block 22)	4050 (200 ksi)	0.95	Water/Concrete Interface	29.2
VI.	24 Mon (Block 8)	4250 (209 ksi)	1.00	Water	28.6

*0.161 in. diameter
 0.020 sq in. cross section
**Ratio of strength of exposed specimens to average strength of unexposed standards.

Table 17
Depth of Corrosion in Copper-Clad Steel Wires*

Block	Exposure Time (mon)	Depth of Corrosion (in.)
19	1	0.047
7	3	0.087
10	3	0.079
9	6	0.224
23	6	0.205
37	6	0.264
38	6	0.256
20	12	0.374
22	12	0.236
29	18	0.512
39	18	0.433
8	24	0.433
21	24	0.433

*All penetration depths are measured on the ends
 submerged in water.

Table 18
Average Corrosion Rates of Various Stainless Steels
(65% Boiling HNO3, ASTM Test A262, Practice C)

Alloy	State	Welding Conditions			Corrosion Rate mils/yr
		Electrode Loading, lb	Secondary Amps	Cycles	
Armco 18-2	AR (1)			--	42.5
	W (1)	390	7000	1	44.3
	AR (2)	-	--		29.4
	W (2)	390	3000	2	49.1
	AR (3)		-	-	39.7
	W (3)	300	3500	3	ND
	S				97.7
AISI 301	AR (1)			--	21.7
	W (1)	600	3000	4	22.9
	AR (2)				18.0
	W (2)	780	7000	5	23.2
	AR (3)				19.9
	W (3)	780	3500	5	22.7
	S				49.5
AISI 201	AR (1)			-	44.3
	W (1)	800	14000	4	57.5
	AR (2)				46.0
	W (2)	1170	17500	5	47.1
	AR (3)				43.8
	W (3)	980	14000	7	54.4
	S				49.0

Table 18 (cont'd)

| Alloy | State | Welding Conditions | | | Corrosion Rate mils/yr |
		Electrode Loading, lb	Secondary Amps	Cycles	
AISI 430	AR (1)				48
	W (1)	800	14000	4	47.4
	AR (2)				48.5
	W (2)	1170	10500	7	49.3
	AR (3)	·			46.8
	W (3)	960	14000	7	58.1
	S			·	71.4
AM 363	AR (1)	·		·	297.5
	W (1)	960	3500	5	326.9
	AR (2)	·		·	ND
	W (2)	960	10500	7	320.2
	AR (3)	·		-	332.7
	W (3)	1170	10500	7	326.9
	S	-	-	··	230.0

AR = as-received, two samples   S = sensitized, four samples
W = welded, one sample   ND = no data condenser broke

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APPENDIX:
PHYSICAL REQUIREMENTS FOR WIRE
FABRIC MATERIALS*

Solicitation No. DACW66-70-R-0050

PART II - TECHNICAL PROVISIONS

SECTION 1 - GENERAL

1-01. General. The intent of these specifications is to secure noncor-
rosive fabric for the manufacture and assembly of articulated concrete mattress
revetment. Articulated concrete mattress units or squares consist essentially
of 20 concrete blocks in which is cast the fabric to form an articulated unit
25 feet by 4 feet. The fabric therefore is used as an assembly system for
inter-connecting the 20 concrete blocks of a concrete mattress unit. To provide
long life, the fabric must be manufactured from a material resistant to corro-
sion when subjected to air, or to water of the Mississippi River, whether alone
or in contact with galvanized or ungalvanized steel, concrete, wood or other
debris, or earth. To provide suitable handling and assembling characteristics,
the fabric must be sufficiently stiff as to not be unduly deformed by normal
handling and yet must be sufficiently flexible to permit the concrete mattress
to conform to the irregularities of the river bed.

1-02. Type of Materials. (See paragraph 2b) The fabric shall be manu-
factured from material having corrosion resistant characteristics equal to or
better than the AISI, Type 301 chrome-nickel steel, or of material with a non-
corrosive metallic covering. Bi-metallic wire shall have a minimum covering
of at least six thousandths (0.006) of an inch in thickness, and in addition
shall have a sufficient thickness of covering to provide the equivalent protec-
tion afforded by a coating of commercially pure copper of six thousandths (0.006)
of an inch properly applied to the steel core. The covering metal must be per-
manently and integrally attached to the core metal and must be uniform, dense,
non-porous, and free from inclusions, laps, seams, splits, checks and slivers
and nodules tending to separate or break away from the wire itself.

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* From *Specifications for End Twist Wires (Wire Forms) and Straight Wires*. Solicitation No.
DACW66-70-R-0050 (Corps of Engineers Memphis District. 1973).

SECTION 2 - FABRIC

2-01. __Physical Requirements__. The fabric shall meet the following requirements:

a. __Size of Wires__. Wire used in manufacturing the fabric shall have a nominal diameter of not less than 0.162 inch nor more than 0.225 inch. Prior to beginning of manufacture, the Contractor shall advise the Contracting Officer of the diameter of the wire he proposes to use. A variation of 2 percent plus or minus from the approved nominal diameter will be permissible.

b. __Fabrication__. The reinforcing fabric shall be manufactured in accordance with the details shown on the attached drawing, Serial No. 14107 File C1/31.1. The end loops shall be parallel to the plane of the fabric assembly within a tolerance of 10 degrees. When the end loop is formed by a mechanical tie, the end bracket wire shall be included in the tie. Joints in longitudinal wires of bi-metallic construction shall be made so that the core metal will be covered with a minimum thickness of ten-thousandths (0.010) of an inch of non-corrosive metal. No portion of the weld of a bi-metallic longitudinal wire shall be more than 5 inches from the nearest bracket wire. Samples of the proposed joint shall be submitted for approval before being used. The joint or splice in the wire forming the bracket wire shall be made within the middle third on the bracket. Brackets may be made from two pieces of wire instead of one, provided that not more than 2 percent of the total number of brackets supplied are made by this method. Bracket wires may be fastened to the longitudinal wire by mechanical or welded ties as shown on the drawing, except that welding of bi-metallic wire that destroys the non-corrosive qualities of the wire will not be permitted. Non-corrosive mechanical ties will not be required. The limits of error permissible in the completed fabric are as follows:

Bracket dimensions: 1/4 inch plus or minus the dimensions
shown on the drawing.

Spacing of wires in fabric: 1/4 inch plus or minus the
position shown on the drawing.

Overall length: 1/2 inch plus or minus the length shown
on the drawing.

End loops: 1/8 inch plus or minus the specified inside
diameter shown on the drawing.

c. __Tensile Strength__. (1) Wire used in manufacturing the fabric shall have a breaking strength of not less than 4,000 pounds in at least 75 percent and not less than 3,600 pounds in the remaining 25 percent of the specimens tested.

(2) __Fabrication Joints__. Any joint or splice in a longitudinal wire shall have a tensile strength at least equal to that specified for the wire. At least 75 percent of the joints or splices in wires used as bracket wires in the fabric shall have a breaking strength of not less than 3,200 pounds, and the remaining 25 percent of the joints or splices in the bracket wires shall have a breaking strength of not less than 2,900 pounds. The end loops in the longitudinal

wires of the fabric shall develop the same breaking strength specified for the
wire. Joints fastening the bracket wires to the longitudinal wires in the
fabric shall not reduce the specified breaking strength of the wires to less than
3,600 pounds and shall have a shearing resistance of not less than 100 pounds.

   d. Bending. The wire from which the fabric is manufactured shall
withstand a minimum of seven 90 degree bends without breaking and shall be capable
of being wrapped around its own diameter 8 consecutive turns with a pitch sub-
stantially equal to the diameter of the wire without signs of imperfections.

   e. Flexibility. The wire used in brackets shall have a permanent
deformation angle between 22 and 35 degrees when subjected to the modified IZOD
Impact Test prescribed in paragraph 2-02e.

  2-02. Tests. The Contractor shall furnish a certified chemical analysis
of each heat of the metal (core metal only for bi-metallic wire), from which wire
for use in fabricating the fabric is drawn. In addition, and at the Contractor's
expense, the finished wire shall be subjected to the following tests to determine
that it meets the requirements of these specifications:

   a. Tensile Strength. Tensile tests to determine the breaking strength
of the fabric wire and various portions of the fabric shall be made as follows:

     (1) Straight unjointed pieces of the wire,

     (2) End loops in each end of the longitudinal wire in the
        fabric,

     (3) Joints or splices in the bracket and longitudinal wire,

     (4) Pieces of wire on which joints fastening bracket wires to
        longitudinal wires have been made,

     (5) Shear tests to determine the strength of joints fastening
        bracket wires to longitudinal wires.

  At least one tensile strength test of the wire shall be made of each coil
of wire approximately 1,000 pounds. One square from each 1,000 squares of fabric
manufactured shall be selected and a tensile strength test made of at least two
end loops in the end of the longitudinal wires; four joints in bracket wires; one
joint or splice in the longitudinal wires; and three pieces of longitudinal wires
and three pieces of bracket wires on which joints fastening bracket wires to
longitudinal wires have been made. From this same square of fabric, three shear-
ing strength tests of the joints fastening bracket wires to longitudinal wires
shall be made. Tests on end loops formed by a mechanical tie shall be made by
holding the longitudinal wire and the two portions of the bent back bracket wire
included in the tie in one jaw of the testing apparatus. The end loop shall be
subjected to a pull applied on the end of the loop through a "U" shaped loop of
wire having a nominal diameter of not less than 0.195 inch nor more than 0.225
inch or through any apparatus which will apply the required pull on the end of the
loop and is so designed that its shape at the point of contact with the loop
simulates that of a wire of not less than 0.195 inch nor more than 0.225 inch
diameter. Tests on end loops formed by a welded tie shall be made by holding the

longitudinal wire outside the limit of the weld in one jaw of the testing apparatus and the remaining portion of the test performed as described above. Should any specimen fail to meet the required tests, such additional tests as necessary to detect any other unsatisfactory wire or fabric shall be made, and all wire or fabric failing to meet the requirements set forth herein shall be rejected.

b. **Bending.** The following tests shall be made from each coil of approximately 1,000 pounds of the wire from which the fabric is to be manufactured.

(1) A length of wire shall be held between jaws having edges rounded on a 3/8" radius. The free end of the wire shall be bent over the rounded edges back and forth through an angle of 180 degrees between limiting positions on opposite sides of, and at right angles to, the original straight wire. Specimens shall be straight and shall extend approximately 10 inches from the support. Bends shall be made at as nearly a uniform speed as possible, not exceeding 50 bends per minute and in no case shall the speed be so great as to cause undue heating of the wire. Each 90° movement in either direction shall be counted as one bend. The number of bends shall be counted until the specimen is severed. When failure occurs, 90 percent of the specimens shall have withstood at least 7 bends. Bi-metallic wire, when broken by repeated bending, shall show no separation of the covering from the core metal.

(2) A length of wire shall be wrapped around its own diameter 8 consecutive turns with a pitch substantially equal to the diameter of the wire without signs of imperfections.

Failure of these tests will result in rejection of the wire represented by the sample.

c. **Quality of Coating of Bi-Metallic Wire.** The following test of the quality of coating of bi-metallic wire shall be made on one specimen from each 200 pounds of wire:

(1) Lengths of wire after having been wrapped as prescribed in paragraph 2-02b(2) shall be subjected to a ferroxyl test to be made as follows:

First: Samples shall be immersed in a 15% solution by
weight of hydrochloric acid for approximately
one hour or longer or in a 25% solution by weight
of hydrochloric acid for approximately 15 minutes
to remove ferrous contamination of the surface.
If surface contamination is still present, the wire
may be immersed for 10 seconds in a 50% solution of
nitric acid.

Second: Sample shall then be immersed for one minute in a
solution of:

10 grams of Potassium Ferricyanide
1000 cc Distilled Water
20 grams of Concentrated Sulphuric Acid

The appearance of blue spots or lines on the samples indicates porosity, flaking, cracks, or interstices showing the solution is in contact with the steel core. If this occurs, four additional specimens shall be prepared and subjected to the ferroxyl test. Failure of any of these retest specimens will result in rejection of material covered by the tests.

(2) The wrapped specimen shall be closely examined to determine any imperfections in the wire. If any inclusions, slivers, cracks or nodules are found in the surface metal the specimen will be subjected to first, the ferroxyl test as described in paragraph 2-02c(1); then to a microscopic examination to determine the thickness of surface metal at the imperfection. Surface metal, not including the imperfection, should be of a minimum thickness as required in paragraph 1-02. If the specimen fails either of the tests, four additional specimens will be examined. Failure of any of the additional specimens will result in rejection of the material covered by the test.

d. Thickness of Coating. Thickness of coating of bi-metallic wire shall be determined by one of the following methods on each 200 pounds of wire from which fabric is to be manufactured:

(1) After thoroughly cleaning the test specimens with carbon tetrachloride, or other grease remover, they shall be immersed in nitric acid for approximately 30 seconds or longer, and then removed and quickly immersed in water to stop the action of the acid. This cycle shall be repeated until the diameter of the wire shall have been reduced at least 2 times the guaranteed minimum thickness of the metallic covering for a length of not less than 1/2 inch. If pitting should occur during this treatment, the specimen shall be burnished with steel wool. At that part of the wire which shows a reduction in diameter of 2 times the guaranteed minimum thickness of the copper covering when measured with a micrometer, the wire shall remain covered with the coating. If any core metal should be visible at any point where the specimen measures two times the guaranteed minimum thickness of the covering less than the original diameter, a microscopic measurement of a duplicate specimen shall be made. Should the microscopic measurement show the covering to be less than the guaranteed minimum thickness of the covering, the coil of wire which the specimen represents shall be rejected.

(2) Removing sufficient coating and accurately gaging with suitably accurate apparatus.

(3) Cutting off the wire, grinding smooth, and etching its exposed cross section, and gaging by suitably accurate apparatus.

(4) Using electrical indicating instruments of suitable accuracy.

e. Flexibility. (1) Materials for bracket wires will be further tested for flexibility. Preliminary investigations indicate that a modification of the IZOD Impact Test (ASTM, E23-47T, Impact Testing of Metallic Materials) will establish the suitability of a type of material, strength and diameter, as affecting flexibility.

(2) The test shall be made with a pendulum type impact machine in the manner prescribed in ASTM, E23-47T for the Cantilever Beam (IZOD type)

tests except that the blow delivered shall be equal to that delivered by the Tinius Olsen apparatus (120 ft. lbs. IZOD capacity) when the pendulum travels 11 inches measured on the chord (the Tinius Olsen machine has a secondary safety stop at this position on the pendulum arm). The mechanism for releasing the pendulum from its initial position shall be such that it operates freely and permits a free start without initial impulse, retardation or side sway.

(3) The specimen shall be a straight wire of the material, strength and diameter proposed. The specimen shall not be notched. The length of the specimen, extending out of the gripping device shall be 28 mm (1.102") and the striking mechanism shall deliver the blow 22 mm (0.866") from the edge of the gripping device.

(4) The striking mechanism will be allowed to deliver only one blow. If the pendulum passes completely over the specimen, the specimen shall be rejected. The specimen shall be removed from the vise after one blow is delivered and the resultant deformation measured. Only materials resulting in a permanent deformation angle between 22 and 35 degrees will be considered satisfactory.

One flexibility test shall be made from each coil of approximately 1,000 pounds of wire.

f. Frequency of Tests. After demonstration of uniformity of quality of production, the frequency of the tests prescribed in paragraphs 2-02a, b. c, d and e above, may be reduced to one test each for each 4,000 pounds of wire from which fabric is to be manufactured and one test for each 4,000 squares of fabric manufactured.

2-03. Packaging. The fabric shall be packed in bundles of 300 squares of fabric laid flat on a stout cradle. The fabric shall be securely fastened or tied on the cradle. The cradles shall be so designed and constructed that handling loops attached to a lifting frame may be swiftly and easily applied to lift the whole cradle and bundle without damage. All fastenings, ties, handling slings, etc., shall be applied in such a manner that the fabric will not be damaged or bent in handling.

All cost of packing and preparing for shipment shall be included in the price bid on the fabric.